Corn Growth Responses to Composted and Fresh Solid Swine Manures

Terrance D. Loecke, Matt Liebman,* Cynthia A. Cambardella, and Tom L. Richard

ABSTRACT

Swine (*Sus scrofa* L.) production in deep-bedded hoop structures is a relatively new swine finishing system in which manure can be applied to fields fresh or after composting. We conducted field-plot trials near Boone, IA, during two growing seasons to determine the effects of fresh and composted swine hoop manures on corn (*Zea mays* L.) growth and yield. Both fresh and composted manures were applied at a total N rate of 336 kg ha^{-1} in the spring before planting corn, and a functional growth analysis approach with frequent plant harvests was used to assess total aerial dry matter (DM) production and leaf area development of the crop. Phytotoxicity bioassays utilizing annual ryegrass (*Lolium multiflorum* Lam.) and cress (*Lepidium sativum* L.) seedlings as test species produced inconsistent responses to manures. During the two seasons in which this experiment was conducted, corn in the composted manure treatment produced 10% more grain than did corn in the fresh manure treatment. Corn treated with composted manure produced 12% greater aboveground DM in 2000 and 15% greater DM in 2001 than did corn treated with fresh manure. In 2000, DM differences were evident early in the season, whereas in 2001, DM differences became evident near flowering. The time of treatment separation in both years coincided with the driest soil conditions of the season. As compared with the fresh manure treatment, composted manure increased corn crop growth rate (CGR), leaf N concentration, leaf area index (LAI), and, in one of two years, net assimilation rate (NAR). Harvest index and leaf area ratio (LAR) were unaffected by manure treatments. Composting swine hoop manure before field application appears to be an effective alternative to fresh-manure application for corn production.

Application of animal manures to agricultural fields is a widely used method of increasing soil organic matter and fertility (Khaleel et al., 1981). Most solid livestock manures can be applied directly to crop fields or piled for composting. Composting manure can reduce field application costs by increasing bulk density and reducing volume. Composting can also increase application uniformity due to a reduction in particle size, and decrease amounts of viable weed seeds (Wiese et al., 1998) and phytotoxic substances (Tiquia and Tam, 1998) contained in manure or manure and bedding mixtures. However, with composting, there are potentially greater production and environmental costs associated with extra handling and possible losses of nutrients. Nitrogen losses during composting of animal manures have ranged from 200 to 700 g kg^{-1} of total N (Martins and Dewes, 1992; Rao Bhamidimarri and Pandey, 1996; Eghball et al., 1997; Tiquia et al., 2002).

Field trials comparing composted with fresh dairy manures have shown similar corn yield (Brinton, 1985; Ma et al., 1999) despite faster seedling growth rates in response to fresh manure (Brinton, 1985). Composted and noncomposted beef feedlot manure applications resulted in similar corn growth rates and grain yields, although lower N-use efficiencies were reported with use of composted manure (Eghball and Power, 1999). Field applications of composted poultry litter resulted in 25% less corn biomass and grain yield than applications of raw poultry litter when these amendments were applied at the same total N rate (Cooperband et al., 2002). The lower N-use efficiency of compost is typically attributed to increased humification of the compost relative to its feedstock, fresh manure. Comparing sunflower (*Helianthus annuus* L.) seedling growth response to composts at increasing stages of humification, Baca et al. (1995) found phytotoxic inhibition from immature composts and Fe, Zn, and N deficiencies with more mature composts. Conversely, a substantial number of studies have demonstrated that animal manures, composts, and compost extracts can increase plant growth beyond levels explainable by increases in nutrient supply (reviewed by Chen and Aviad, 1990). Because of these potentially contradictory effects, the impacts of fresh and composted manures on crop performance cannot yet be predicted with confidence.

Swine production in hoop structures is a relatively new husbandry system in which deep-bedded manure can be either spread directly or composted before use (Honeyman et al., 2001). A comparison of composted and fresh swine hoop manures on crop performance is relevant to the development of best management practices for utilizing manure. Quantitative growth analysis can be used to make such comparisons and may provide important insights into the dynamics of crop × climate × soil interactions that will ultimately affect yield (Evans, 1972; Hunt, 1982). The objective of this study was to use a quantitative growth analysis approach to examine corn responses to spring-applied composted and fresh hoop manures under field conditions.

MATERIALS AND METHODS

Site, Experimental Design, and Management

The experiment was conducted on adjacent fields during 2000 and 2001 at Iowa State University's Agronomy and Agricultural Engineering Research Farm near Boone, IA (42°01′ N, 93°45′ W). Both field sites were in a soybean [*Glycine max* (L.) Merr.]–corn–oat (*Avena sativa* L.) rotation with no animal

T.D. Loecke, Dep. of Crop and Soil Sci., Michigan State Univ., 562 Plant and Soil Sciences Bldg., East Lansing, MI 48824-1325; M. Liebman, Dep. of Agronomy, 3405 Agronomy Hall, Iowa State Univ., Ames, IA 50011-1010; C.A. Cambardella, USDA-Agricultural Research Service, 310 National Soil Tilth Lab., Ames, IA 50011-3120; T.L. Richard, Dep. of Agricultural and Biosystems Engineering, 3222 National Swine Research and Information Center, Iowa State Univ., Ames, IA 50011-3080. Received 30 Dec. 2002. *Corresponding author (mliebman@iastate.edu).

Published in Crop Sci. 44:177–184 (2004).

677 S. Segoe Rd., Madison, WI 53711 USA

Abbreviations: CGR, crop growth rate; DAP, days after planting; DM, dry matter; GDD, growing degree days; LAI, leaf area index; LAR, leaf area ratio; NAR, net assimilation rate.

manure application history in the previous 10 yr. The soil of the 2000 site was a Nicollet loam (fine-loamy, mixed, superactive, mesic Aquic Hapludolls), whereas the 2001 site was mainly a Webster silty clay loam (fine-loamy, mixed, superactive, mesic, Typic Endoaquolls). Air temperature and precipitation data were collected from an automated weather station located within 1 km of the study area. Soil moisture concentration in the surface 20 cm of soil was determined gravimetrically every 7 to 21 d throughout the growing seasons from three 20-cm by 4.4-cm-diam. soil cores taken from each plot.

A randomized complete block design with four replications was used. Plots consisted of five corn rows spaced 0.76 m apart, and were 61 m in length in 2000 and 73 m in 2001. On 21 Apr. 2000 and 24 Apr. 2001, fresh and composted hoop manures were applied to appropriate plots at a rate of 336 kg of total N ha^{-1}. This rate was based on the assumption that approximately one-third of the total N (i.e., 112 kg N ha^{-1}) would be plant-available in the first year after application (Eghball and Power, 1999). A rear-discharge manure spreader was calibrated by adjusting tractor and spreader-gear speeds to apply the desired mass of each manure to a tarp of known area. The manures were incorporated with a disk into the surface 15 cm of soil within 6 h of application. In 2000, two passes with a cultipacker were also necessary for adequate seedbed preparation. The manures were obtained from the Iowa State University Rhodes Research Farm in Marshall County, Iowa, except for the fresh manure applied in the spring of 2001, which was from a commercial farm in Story County, Iowa.

A corn hybrid (Pioneer 35P12, Pioneer Hi-Bred International Inc., Johnston, IA) was planted at 140 000 seeds ha^{-1} on 5 May 2000 and 9 May 2001, and then thinned to an evenly spaced population of 71 000 plants ha^{-1} at Plant Growth Stage V1 (Hanway, 1963). Weed control was achieved with a preplant-incorporated application of metolachlor [2-chloro-*N*-(2-ethyl-6-methylphenyl)-*N*-(2-methoxy-1-methylethyl) acetamide] at 1.5 kg a.i. ha^{-1}, interrow cultivation at Plant Growth Stage V6, and hand weeding.

Manure characteristics were determined for 4-L composite samples collected from twenty 0.18-m^2 plastic trays placed inside the spreader path in each plot at the time of application. Manure samples were stored at −20°C in plastic freezer bags, then thawed, homogenized, separated for various analyses (total C, N, P, K, NH_4^+–N, NO_3^-–N, moisture and ash concentration, pH, electrical conductivity, and phytotoxicity bioassay), and then refrozen until individual parameters were analyzed. Manure total C and N were determined after acidification with 0.5*M* HCl (1:2 sample:solution ration), air drying, and grinding, by dry combustion in a Carlo-Erba NA1500 NCS elemental analyzer (Haake Buchler Instruments, Paterson, NJ) as described by Cambardella et al. (2003). Total P and K were determined on dried ground samples by USEPA Method 3051 at a commercial laboratory (Midwest Laboratory, Inc., Omaha, NE). Ammonium-N and nitrate-N were determined by 2 *M* KCl extracts (1:80 manure:solution ratio) and Lachat flow-analysis (Lachat Instruments, Milwaukee, WI) (Keeney and Nelson, 1982). Manure moisture concentration was determined by drying at 70°C for 48 h, ash concentration was determined by ignition at 550°C, and pH and electrical conductivity were determined in a 1:5 manure:water slurry.

Phytotoxicity Bioassay

Phytotoxicity bioassays were conducted with a germination method modified from one given by Zucconi et al. (1981). Homogenized manure samples (70 g of dry-weight equivalent thawed manures) and distilled water were combined to achieve a 100 g kg^{-1} concentration by mass solution that was shaken for 15 h at 22°C, passed through cheesecloth, and centrifuged at 3000 × *G* for 30 min at 22°C. The supernatant was then diluted to a 50 g kg^{-1} concentration by mass with distilled water and centrifuged at 4900 × *G* for 10 min at 22°C. This supernatant was used as the test extract. Thirty seeds of cress or annual ryegrass were placed on two layers of Fisher Qualitative P5 filter paper (Fisher Scientific, Brightwaters, NY) in sterile Petri dishes (100 × 15 mm) and 2.5 mL of the extract was filtered through a 0.45-μm Cameo Syringe Filter (Minnetonka, MN) and applied onto the seeds. Five Petri dish replicates of each species were incubated in a completely randomized arrangement in alternating conditions of 30°C (16 h of light) and 20°C (8 h of dark). After 4 d, growth was terminated by applying a 50% ethanol solution, and radicle length was measured. A radicle length < 0.5 mm was recorded as zero. Percentage radicle length inhibition (RI%) was calculated as:

$$RI\% = -1(RL_{water} - RL_{manure})/RL_{water} \times 100,$$

where RL_{water} is the mean radicle length from a distilled water control treatment, and RL_{manure} is the mean radicle length from the aqueous manure extract. Results are reported such that a negative RI% indicates inhibition and a positive RI% indicates stimulation as compared with seeds treated with the distilled water control. Two sets of bioassays were conducted for each manure sample.

Plant Sampling Procedures

All measurements in the field experiments were taken from the center three rows of each plot. At Plant Growth Stage V1, each plot was divided into subplots for determination of aboveground DM production and grain yield. Thirty-nine randomly selected subplots, each containing four equally spaced plants, were established for DM harvest within each plot. For grain harvest, one three-row-by-9.1-m and two three-row-by-11.0-m grain yield harvest subplots were randomly located within each plot in 2000 and 2001, respectively. Three DM subplots per plot were harvested every 7 to 16 d from Growth Stages V1 to R6 for a total of 13 harvest dates in 2000 and 11 in 2001. Plants were separated into two components in the field: leaf (blade only) and nonleaf (stalk, leaf sheath, and reproductive parts). Leaf area was determined using a bench-top leaf area meter (LI-3100 Area Meter, LI-COR, Inc., Lincoln, NE) within 3 h of harvest. Both leaf and nonleaf components were then dried at 60°C in paper bags for a minimum of 4 d and weighed. Starting at Plant Growth Stage R1, the wet weight of the complete nonleaf component was determined, but only a representative sample (approximately equal to two plants in mass and composition) was dried and used in subsequent analyses.

Corn in grain yield subplots was harvested with a combine equipped with a weigh tank and an on-board moisture meter. For ease of comparison, both grain yields and DM are reported on a 0 g kg^{-1} moisture concentration basis.

All dried plant tissues (leaf, nonleaf, and grain) were ground to pass a 0.85-mm screen and sent to a commercial laboratory (Harris Laboratory, Lincoln, NE) for total N analysis as determined by Kjeldahl digestion procedures. Fifteen stalk samples (20 cm in length) were collected 15 cm above the soil surface from each plot at grain harvest, then dried at 60°C for 4 d, ground to pass a 0.85-mm screen, and analyzed for NO_3^-–N (Binford et al., 1992).

The functional approach to growth analysis (Hunt, 1982) was used to analyze aerial DM per plant (W) and leaf area per plant (A) in a manner similar to methods used by Bullock et al. (1988). Briefly, the approach involved using repeated observations of each plot to generate plot-specific curves of W vs. GDD and A vs. GDD, where GDD is growing degree days accumulated after planting. We defined GDD mathematically as:

$$GDD = [(T_{max} + T_{min})/2] - T_B,$$

where T_{max} is the daily maximum air temperature, T_{min} is the daily minimum air temperature, and T_B is equal to 10°C, the physiological minimum base temperature for corn growth. Plot-specific DM and leaf area curves were then used to generate predicted values at particular GDDs. Analyses of variance were performed on predicted values. As noted by Vernon and Allison (1963) and Hunt (1982), analysis of predicted variables obtained from curves fitted to data from individual plots is advantageous because it draws on observations made throughout the season to provide a more precise picture of plant growth dynamics. Russelle et al. (1984) have described the rationale for the use of GDD rather than calendar date as an independent variable.

Specific details of the analysis presented here are as follows. After examination of several possible functions (Hunt, 1982) for goodness of fit and systematic biases, the Gompertz (Sit, 1994) function was fitted to W and a weighted third-order polynomial was fitted to *A*. Dry matter per plant (W) was fitted using PROC NONLIN in SAS (SAS Institute, 1999) with programming code from Sit (1994). Leaf area per plant (A) was fitted with PROC REG in SAS with a weight inversely proportional to the GDD. This weighted least squares procedure was used to offset the observed increase in variation associated with increasing leaf area through time. A third-order polynomial was fitted to the leaf N concentrations and was subjected to the same analysis as A and W using PROC REG in SAS. Predicted W, A, and leaf N concentration values were calculated for each replicate plot at approximately the same GDD at which they were harvested.

From these predicted plant growth parameters, equations provided by Hunt (1982) were used to examine plant growth rates, growth efficiencies, and morphological patterns. In this paper we examine CGR, which describes the rate of DM accumulation on a unit ground area basis; LAI, which describes leaf surface area on a unit ground area basis; NAR, which is a measure of how efficiently the crop produces new DM with its leaf area; and LAR, which is a means of expressing the proportion of the aboveground DM that is partitioned into leaf area. The following equations describe these variables:

$$CGR = n(dW/dGDD)$$

$$LAI = nA$$

$$NAR = (1/A) \times (dW/dGDD)$$

$$LAR = A/W$$

where n is the number of crop plants per unit ground area.

Statistical Analysis

Analysis of variance was conducted by the PROC GLM routine of SAS (SAS Institute, 1999) to test for main and interactive effects of years, blocks, and treatments on plant growth parameters. If year × treatment interactions were nonsignificant, then the sums of squares attributed to this component of the ANOVA was pooled with the experimental error sums of squares to test for significant year and treatment effects (Underwood, 1997). Phytotoxicity bioassay data were tested for treatment × trial interactions by ANOVA, and homogeneity of between-trial error variances was tested by Cochran's procedure (Underwood, 1997). Means from the phytotoxicity bioassays were separated by Fisher's least significant difference procedure.

RESULTS AND DISCUSSION

Manure Characteristics

The average C:N ratio was 12.8:1 for fresh and 11.8:1 for composted manures (Table 1). Materials with C:N ratios < 20:1 are generally thought not to immobilize soil N following application and soil incorporation (Mathur et al., 1993), although short-term immobilization has been observed with partially composted hoop manure with C:N ratios of 12:1 to 15:1 (Cambardella et al., 2003). The composition of the fresh manure was similar in both 2000 and 2001, with the exception of a more than two-fold higher NH_4^+–N concentration in 2000 compared with 2001. The C concentration of the compost applied in 2001 was much greater than that applied in 2000. This was probably because of colder-than-normal weather conditions during the composting period of winter 2000-2001, which may have slowed decomposition compared with the warm winter of 1999-2000. The higher NO_3^-–N and ash concentrations in the compost applied in 2000 also indicate that the 2000 compost was more decomposed than the 2001 compost.

Cress and ryegrass germination and radicle growth have been used to detect the presence of phytotoxins in compost that may temporarily or permanently inhibit crop growth (Iannotti et al., 1994; Pare et al., 1997). However, these parameters may not provide complete information about compost phytotoxicity and maturity (Zucconi et al., 1981). In the present study, each of the manures used in the bioassays stimulated cress radicle growth compared with the distilled water control treatment, with the fresh manure applied in 2001 being the most stimulatory (Table 1). In contrast, fresh manure applied in 2000 inhibited ryegrass radicle growth relative to the distilled water control. These test-plant-species × manure-form interactions indicate that the bioassays were inconclusive in determining phytotoxic effects.

Table 1. Selected chemical, physical, and biological parameters of organic manures applied in 2000 and 2001 near Boone, IA.

	2000		2001	
Manure parameters	**Compost**	**Fresh**	**Compost**	**Fresh**
Water, g kg^{-1}†	264	546	485	547
Ash, g kg^{-1}	714	439	594	434
C, g kg^{-1}	129	254	201	243
N, g kg^{-1}	11.7	21.0	16.4	18.3
P, g kg^{-1}	8.7	9.7	6.3	9.2
K, g kg^{-1}	15.4	21.5	15.5	16.7
NH_4^+–N, μg g^{-1}	1110	4980	600	2000
NO_3^-–N, μg g^{-1}	550	80	60	50
C:N	11.0	12.3	12.3	13.3
pH	8.1	8.4	8.6	8.4
Electrical conductivity, S m^{-1}	0.56	0.51	0.37	0.29
Phytotoxicity‡				
Cress, %	17.7a	26.1a	46.8a	102.6b
Ryegrass, %	9.4b	−13.7a	8.6b	20.1b

† Water concentration is expressed on a wet weight basis, all other concentration parameters are expressed on a dry weight basis.

‡ A positive response denotes stimulation and a negative response signifies inhibition relative to distilled water control. Within rows, means followed by the same letter are not significantly different according to LSD ($\alpha = 0.05$).

Growth Responses

Treatment × GDD × year interaction terms were significant for DM responses, so results are presented by year. Corn in composted manure-treated soils produced 12% greater aboveground DM in 2000 and 15% greater DM in 2001 than did corn in fresh-manure-treated soils (Fig. 1). Dry matter production in plots receiving composted manure was higher throughout the entire 2000 season with the exception of the first harvest. In 2001, DM accumulation was higher for composted-manure-treated soils during the latter half of the growing season (Fig. 1). In 2000, early season CGR of fresh-manure-treated plots was slower than composted-manure-treated plots. The reason for this seedling vigor difference in 2000 is unclear. The intentional thinning of the plant population to the desired density eliminated the possibility of treatment differences in seedling emergence. Although dry soil conditions were present in both treatments at corn planting in 2000 (Fig. 2), fresh-manure clods remained on the soil surface despite preplant tillage. These fresh-manure clods may have had physical or chemical effects on plant vigor. This was in contrast to the finer particle size of composted manure that was completely incorporated into the soil with tillage. The phytotoxicity bioassay response of ryegrass displayed a trend similar to the growth of corn seedlings in 2000 (Table 1). The ryegrass radicle growth was inhibited by the fresh manure applied in 2000 as opposed to the stimulatory effects of the composted manure applied in 2000. However, the cress radicle growth response to these manures did not show a similar trend. In 2001, no inhibitory effects of the applied manures were detected on the corn seedlings grown in the field (Fig. 1) or the ryegrass or cress bioassays (Table 1). Moist soil conditions in 2001 (Fig. 2) also aided in the breakup of fresh-manure clods by preplant tillage.

The time of 50% silk emergence occurred at 76 days after planting (DAP) (or 760 GDD) in 2000 and 74 DAP (or 780 GDD) in 2001 (Fig. 3). In 2000, the timing and magnitude of the maximum CGR (2.75 g m^{-2} GDD^{-1} at 750 GDD) (Fig. 1) and the leaf N concentrations during flowering (Fig. 4) were similar for each treatment, suggesting that the treatments had no effect on the timing of plant transition from vegetative to reproductive stages. The LAI of compost-treated plots was greater than the fresh-manure-treated plots throughout the 2000 growing season (Fig. 5). As a result of the parallel increase in DM production, the treatments were equally efficient at producing biomass from a given LAI;

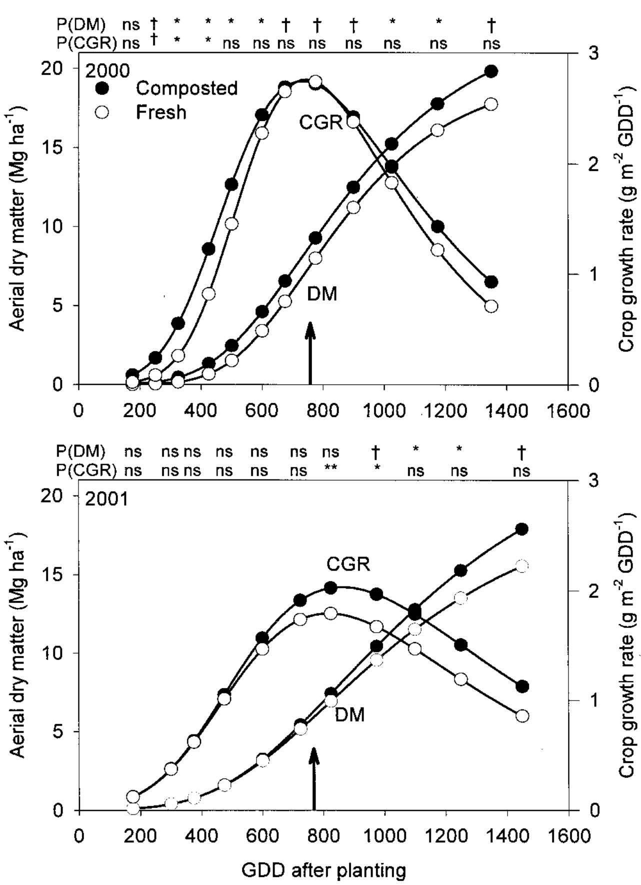

Fig. 1. Mean predicted corn aerial dry matter (DM) and crop growth rate (CGR) as functions of the cumulative growing degree days (GDD) after corn planting in 2000 and 2001 near Boone, IA. The P(DM) and P(CGR) symbols represent the probabilities of significant differences between corn response to composted swine hoop manure and fresh swine hoop manure. †, *, and ** represent significance at the 0.1, 0.05, and 0.01 probability levels, respectively. The black arrow in each figure represents the time of 50% silk emergence, Plant Growth Stage R1.

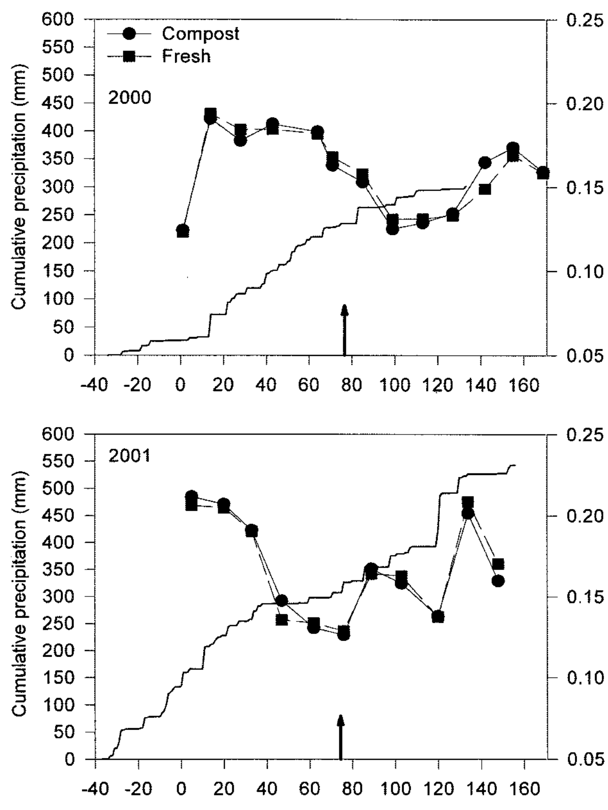

Fig. 2. Cumulative growing season precipitation (from 1 April to grain harvest) and moisture concentration of the surface 20 cm of soil during the 2000 and 2001 growing seasons near Boone, IA. The black arrow in each figure represents the time of 50% silk emergence, Plant Growth Stage R1.

that is, NAR did not differ significantly between treatments in 2000 (Fig. 5).

In 2001, composted manure produced a greater (2.0 vs. 1.8 g m^{-2} GDD^{-1}) and slightly later (880 vs. 820 GDD) maximum CGR than did the fresh manure, leading to greater late-season biomass production (Fig. 1). This greater late-season biomass production in the composted manure treatment was maintained through a longer leaf area duration, as indicated by the treatment differences in LAI at the last measurement date (Fig. 5) and the trend for leaf N concentration to be greater in the composted treatment at that point in the season (700 to 950 GDD) (Fig. 4). The composted manure treatment also had a greater NAR in the later part of the 2001 season (Fig. 5). The observed senescence of leaf area and reduction in leaf N concentration in the fresh-manure-treated plants relative to the compost treatment in 2001 resembles effects commonly attributed to either water (Westgate and Thomson Grant, 1989) or N (Uhart and Andrade, 1995) deficits. However, no treatment differences were detected in the surface 20 cm of soil at any time during 2001 in either soil moisture concentration (Fig. 2), or in plant-available soil N (unpublished data). It is interesting to note that the period of treatment separation bracketing flowering in 2001 had the warmest (Fig. 3) and the driest (Fig. 2) conditions of the season. If plant water or N status contributed to this treatment separation in growth, then the compost-treated plants were either more efficient at utilizing nutrients from the surface 20 cm of soil or the zone of active water or N uptake differed between treatments.

Leaf area ratio, the plant partitioning ratio of LAI to

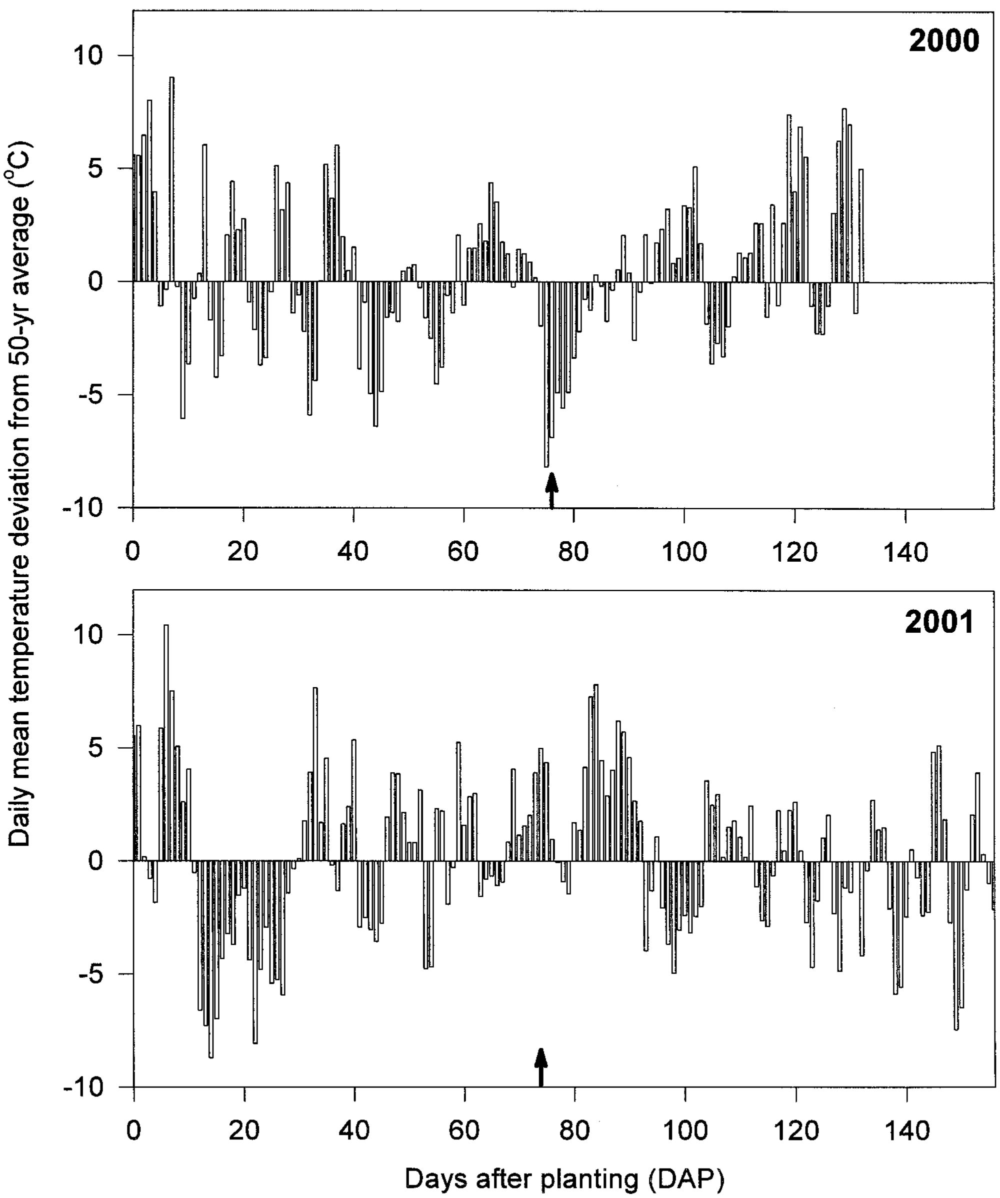

Fig. 3. Daily mean air temperature deviations from the 50-yr average during the 2000 and 2001 growing seasons, near Boone, IA. The black arrow in each figure represents the time of 50% silk emergence, Plant Growth Stage R1. Note the intense warm period at Plant Growth Stage R1 in 2001 relative to 2000.

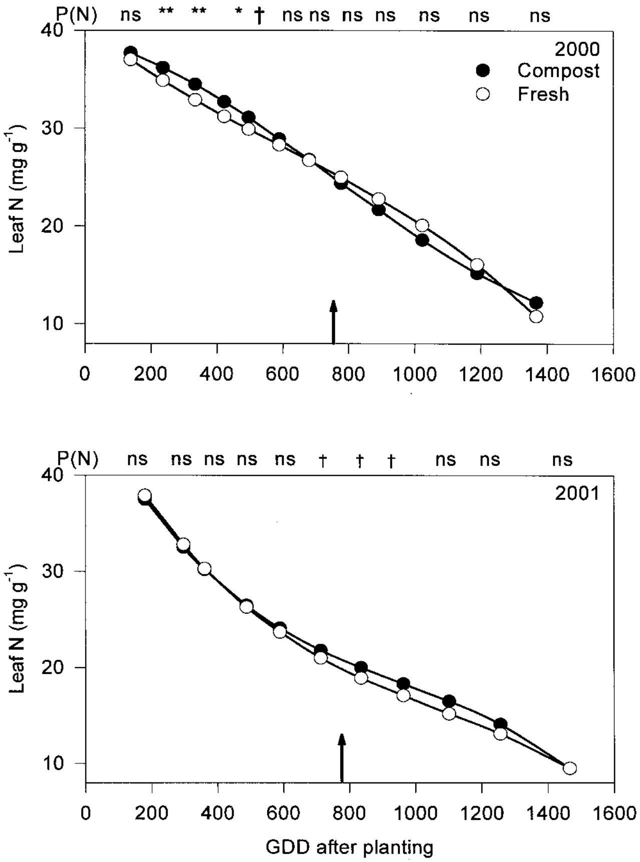

Fig. 4. Mean predicted corn leaf N concentrations as functions of cumulative growing degree days (GDD) after corn planting in 2000 and 2001 near Boone, IA. The P(N) symbols represent the probabilities of significant differences between corn response to composted swine hoop manure and fresh swine hoop manure from similar origins. †, *, and ** represent significance at the 0.1, 0.05, and 0.01 probability levels, respectively. The black arrow in each figure represents the time of 50% silk emergence, Plant Growth Stage R1.

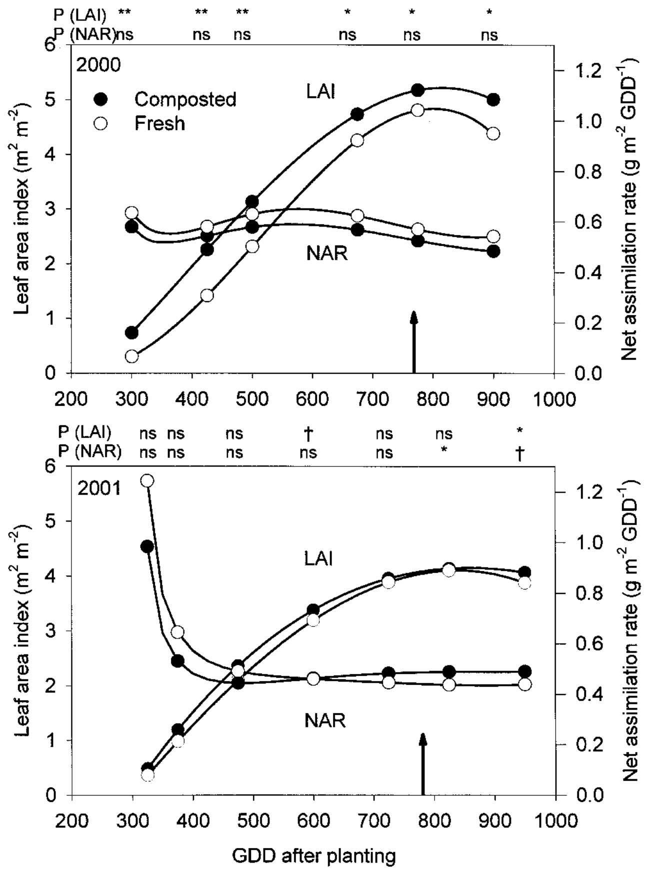

Fig. 5. Mean predicted corn leaf area index (LAI) and net assimilation rate (NAR) as functions of the cumulative growing degree days (GDD) after corn planting in 2000 and 2001 near Boone, IA. The P(LAI) and P(NAR) symbols represent the probabilities of significant differences in corn responses to composted swine hoop manure and fresh swine hoop manure. †, *, and ** represent significance at the 0.1, 0.05, and 0.01 probability levels, respectively. The black arrow in each figure represents the time of 50% silk emergence, Plant Growth Stage R1.

DM, was consistent between treatments in both years (data not shown), indicating that the form of manure applied did not alter this morphological characteristic.

Grain Yield, Fall Stalk Nitrate Concentration, and Dry Matter Harvest Index

Analysis of variance conducted for grain yield, fall stalk nitrate concentration, and DM harvest index indicated that there were no significant treatment × year interactions for these response variables (Table 2). In both years, composted-manure applications resulted in greater corn grain yields than did fresh manure. Also, grain yield was higher in 2000 than in 2001, despite greater total seasonal precipitation in 2001 (Fig. 2). Note that the time period bracketing flowering was cooler than normal in 2000 and warmer than normal in 2001 (Fig. 3). Heat and moisture stress during flowering can have significant impacts on pollination and kernel development (Westgate and Thomson Grant, 1989).

Yield results in the present study are contrary to those from the studies conducted by Brinton (1985) and Eghball and Power (1999), which showed similar yields with fresh and composted manures. However, in the latter two studies, composted manure was applied at higher total N rates than the noncomposted manures, and consequently lower N-use efficiency resulted from the use of composted manure relative to noncomposted manure. Composted and fresh manures were applied at equivalent total N rates in the present study and in the investigation by Cooperband et al. (2002) of corn responses to composted and fresh poultry litter. Cooperband et al. (2002) found, however, that composted poultry litter resulted in lower corn biomass and grain yields than did raw poultry litter. Thus, our results are unique in showing higher grain yields and greater N-use efficiencies from composted relative to fresh manures. We know of no other experiments comparing the effects of fresh and composted swine manures on corn yield.

Corn stalk samples (20-cm segment taken at 15 cm up the stalk from the soil surface) taken at physiological maturity (Growth Stage R6) have been used to indicate late-season soil N availability or plant stress (Binford et al., 1992). In Iowa, Binford et al. (1992) set a stalk NO_3^-–N concentration of >2000 μg g^{-1} to indicate excessive soil NO_3–N and <200 μg g^{-1} as an indicator of

Table 2. Analysis of variance and means of corn grain yield, fall stalk nitrate concentration, and harvest index in response to fresh and composted swine manure applied during 2000 and 2001 near Boone, IA.

Treatment	df	Grain yield†	Fall stalk NO_3^-–N	Harvest index‡
		Mg ha^{-1}	μg g^{-1}	
2000				
Composted manure		9.3	920	0.47
Fresh manure		8.6	471	0.48
2001				
Composted manure		8.2	92	0.46
Fresh manure		7.3	66	0.47
2-yr average				
Composted manure		8.7	506	0.46
Fresh manure		7.9	269	0.48
Source of Variation			$P > F$	
Year (Y)	1	0.002	0.082	0.254
Treatment (T)§	1	0.005	0.495	0.168
Y × T	1	0.615	0.562	0.159

† Grain yield data were adjusted to a moisture concentration of 0 g kg^{-1}.
‡ Harvest index is the ratio between grain dry matter and total plant dry matter.
§ Treatment F test was conducted with the pooled error (T × B + T × Y × B), with B = blocks.

insufficient inorganic soil N for maximum grain yield. We found no stalk NO_3–N concentration differences between treatments, but a trend for higher stalk NO_3–N concentrations in 2000 than in 2001 (Table 2). In 2001, stalk NO_3–N concentrations in both the fresh-manure and compost treatments were <200 μg g^{-1} (Table 2), indicating that additional plant-available N would likely have increased corn grain yield (Binford et al., 1992). Eghball and Power (1999) found no stalk nitrate concentration differences between composted and noncomposted manure treatments, but found that stalk nitrate concentrations in these treatments were lower than in synthetic N fertilizer treatments, despite similar grain yields.

CONCLUSIONS

During the two seasons in which this experiment was conducted, corn in the composted manure treatment produced 10% more grain than did corn in the fresh manure treatment. Corn in composted-manure-treated soils produced 12% greater aboveground DM in 2000 and 15% greater DM in 2001 than did corn in fresh-manure-treated soils. The higher yields from compost were achieved by greater LAI and leaf area duration in both years. Morphological plant traits (LAR and DM harvest index) were not affected by composting manure before application, but a physiological trait (NAR) was; compost-treated soils produced plants with greater NAR after flowering in 2001 than did fresh-manure-treated soils. Phytotoxicity bioassays with ryegrass and cress seedlings were inconclusive in predicting in-field corn seedling responses to manures. An interesting crop-climate-soil observation was that in both years, the time of DM treatment separation coincided with the driest soil conditions of each growing season, despite a lack of detectable soil moisture concentration differences between treatments. Composting swine hoop manure before field application appears to be an effective alternative to fresh-manure application for corn production.

ACKNOWLEDGMENTS

Partial funding for this work was provided by the Leopold Center for Sustainable Agriculture (Project 2000-42), the Iowa Dep. of Natural Resources (Project 00-G550-01CG), and Chamness Technology, Inc. (Project 1221). We thank J. Ohmacht, D. Sundberg, and R. Vandepol for technical assistance in the field and laboratory.

REFERENCES

Baca, M.T., I.C. Delgado, M. De Nobili, E. Esteban, and A.J. Sanchez-Raya. 1995. Influence of compost maturity on nutrient status of sunflower. Commun. Soil Sci. Plant Anal. 26:169–181.

Binford, G.D., A.M. Blackmer, and B.G. Meese. 1992. Optimal concentrations of nitrate in cornstalks at maturity. Agron. J. 84:881–887.

Brinton, W.F., Jr. 1985. Nitrogen response of maize to fresh and composted manure. Biol. Agric. Hortic. 3:55–64.

Bullock, D.G., R.L. Nielsen, and W.E. Nyquist. 1988. A growth analysis comparison of corn grown in conventional and equidistant plant spacing. Crop Sci. 28:254–258.

Cambardella, C.A., T.L. Richard, and A. Russell. 2003. Compost mineralization in soil as a function of composting process conditions. Eur. J. Soil Biol. (in press).

Chen, Y., and T. Aviad. 1990. Effects of humic substances on plant growth. p. 161–186. *In* P. MacCarthy et al. (ed.) Humic substances in soil and crop sciences: Selected readings. ASA and SSSA, Madison, WI.

Cooperband, L., G. Bollero, and F. Coale. 2002. Effect of poultry litter and composts on soil nitrogen and phosphorus availability and corn production. Nutr. Cycling Agroecosyst. 62:185–194.

Eghball, B., and J.F. Power. 1999. Composted and noncomposted manure application to conventional and no-tillage systems: Corn yield and nitrogen uptake. Agron. J. 91:819–825.

Eghball, B., J.F. Power, J.E. Gilley, and J.W. Doran. 1997. Nutrient, carbon, and mass loss of beef cattle feedlot manure during composting. J. Environ. Qual. 26:189–193.

Evans, G.C. 1972. The quantitative analysis of plant growth. Blackwell Scientific Publ., Oxford, UK.

Hanway, J.J. 1963. Growth stages of corn. Agron. J. 55:487–492.

Honeyman, M.S., J.D. Harmon, J.B. Kliebenstein, and T.L. Richard. 2001. Feasibility of hoop structures for market swine in Iowa: Pig performance, pig environment, and budget analysis. Appl. Eng. Agric. 17:869–874.

Hunt, R. 1982. Plant growth curves: The functional approach to plant growth analysis. Univ. Park Press, Baltimore, MD.

Iannotti, D.A., M.E. Grebus, B.L. Toth, L.V. Madden, and H.A. Hoitink. 1994. Oxygen respirometry to assess stability and maturity of composted municipal solid waste. J. Environ. Qual. 23:1177–1183.

Keeney, D.R., and D.W. Nelson. 1982. Nitrogen-inorganic forms. p. 643–698. *In* A.L. Page et al. (ed.) Methods of soil analysis. Part 2. 2nd ed. Agron. Monogr. 9. ASA and SSSA, Madison, WI.

Khaleel, R., K.R. Reddy, and M.R. Overcash. 1981. Changes in soil physical properties due to organic waste application: A review. J. Environ. Qual. 110:133–141.

Ma, B.L., L.M. Dwyer, and E.G. Gregorich. 1999. Soil nitrogen amendment effects on nitrogen uptake and yield of maize. Agron. J. 91: 650–656.

Martins, O., and T. Dewes. 1992. Loss of nitrogenous compounds during composting of animal wastes. Bioresour. Technol. 42:103–111.

Mathur, S.P., G. Owen, H. Dinel, and M. Schnitzer. 1993. Determination of compost biomaturity: I. Literature review. Biol. Agric. Hortic. 10:65–85.

Pare, T., E.G. Gregorich, and H. Dinel. 1997. Effects of stockpiled and composted manures on germination and initial growth of cress (*Lepidium sativum*). Biol. Agric. Hortic. 14:1–11.

Rao Bhamidimarri, S.M., and S.P. Pandey. 1996. Aerobic thermophilic composting of piggery solid wastes. Water Sci. Technol. 33:89–94.

Russelle, M.P., W.W. Wilhelm, R.A. Olson, and J.F. Power. 1984. Growth analysis based on degree days. Crop Sci. 24:28–32.

SAS Institute. 1999. The SAS system for Windows. Release 8.0. SAS Inst., Cary, NC.
Sit, V. 1994. Catalog of curves for curve fitting. Biometrics information handbook series. Forest Sci. Res. Branch of Ministry of Forests, Victoria, BC, Canada.
Tiquia, S.M., T.L. Richard, and M.S. Honeyman. 2002. Carbon, nutrient, and mass loss during composting. Nutr. Cycling Agroecosyst. 62:15–24.
Tiquia, S.M., and F.Y. Tam. 1998. Elimination of phytotoxicity during co-composting of spent pig-manure sawdust litter and pig sludge. Bioresour. Technol. 65:43–49.
Uhart, S.A., and F.H. Andrade. 1995. Nitrogen deficiency in maize: I. Effects on crop growth, development, dry matter partitioning, and kernel set. Crop Sci. 35:1376–1383.
Underwood, A.J. 1997. Experiments in ecology: Their logical design and interpretation using analysis of variance. Cambridge Univ. Press, Cambridge, UK.
Vernon, A.J., and J.C.S. Allison. 1963. A method of calculating net assimilation rate. Nature (London) 200:814.
Westgate, M.E., and G.L. Thomson Grant. 1989. Water deficits and reproduction in maize. Response of the reproductive tissue to water deficits at anthesis and mid-grain fill. Plant Physiol. 91:862–867.
Wiese, A.F., J.M. Sweeten, B.W. Bean, C.D. Salisbury, and E.W. Chenault. 1998. High temperature composting of cattle feedlot manure kills weed seed. Appl. Eng. Agric. 14:377–380.
Zucconi, F., A. Pera, M. Forte, and M. de Bertoldi. 1981. Evaluating toxicity of immature compost. BioCycle 22:27–29.